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Effect of brief, repeated hyperbaric exposures on susceptibility to nitrogen narcosis

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Rogers WH, Moeller G. Effect of brief, repeated hyperbaric exposures on susceptibility to nitrogen narcosis. Undersea Biomed Res 1989; 16(3):227–232.—We investigated the effect of brief, repetitive exposures to 5.5 ATA (148 fsw) in a hyperbaric chamber on adaptation to nitrogen narcosis. A standing-steadiness task, which measures body sway, was administered to 2 groups of 3 chamber-qualified men at 5.5 ATA and 1.3 ATA [10 fsw (control)] on each of 12 successive days to determine if an initial performance decrement at 5.5 ATA would be ameliorated with time. Standing steadiness was significantly worse at 5.5 ATA than at 1.3 ATA across all 12 exposures. There were also changes in standing steadiness from day to day, but these changes occurred in both the test and control depths. There was no day-×-depth interaction that would have indicated that the initial performance decrement at 5.5 ATA was reduced with repetitive exposures. These results are taken as evidence that there is little or no behavioral adaptation to nitrogen narcosis in response to brief, repetitive exposures to narcosis-inducing hyperbaric air.

repetitive diving
inert gas narcosis
stabilimeter

One of the limitations of breathing compressed air at moderate underwater depths [4–8.5 atmospheres absolute (ATA) or about 100–250 fsw] or of exposure to comparable hyperbaric conditions, as in pressure chambers, is the behavioral impairment that commonly occurs. This behavioral impairment and related subjective changes are caused by the narcotic effect of the increased partial pressure of nitrogen, that is, nitrogen narcosis (1). Depending on the context, nitrogen narcosis may refer to a behavioral impairment, or to the narcotic effect, or to both. Humans subjected to these conditions typically behave and report feeling as though they are intoxicated. The degree of intoxication caused by hyperbaric air increases as the pressure of the inspired air increases.

A series of studies performed at this laboratory has been aimed at finding ways of reducing the behavioral impairment resulting from nitrogen narcosis. Although replacing the nitrogen in the breathing mixture with helium eliminates the narcotic effects, the expense and rarity of helium make it an impractical solution for all situations. Hence, the emphasis has been on methods that reduce narcosis at moderate depths or in a comparable hyperbaric environment, without resort to a more expensive breathing mixture.

The primary focus of these studies has been on whether humans adapt to the effects of hyperbaric nitrogen so that behavioral impairments are reduced or eliminated with repeated or prolonged exposure. We believe that the evidence against adaptation is strong (2). In direct empirical tests for adaptation to narcosis, Moeller et al. (3) found no behavioral evidence of adaptation in two separate studies. The first study involved four 45-min exposures to 6.7 ATA (188 fsw) spaced 3 days apart, and the second study involved five daily 45-min exposures to 6.6 ATA (185 fsw) 1 day apart. Moeller et al. (3) used a method in which performance on a battery of behavioral measures, including motor and cognitive tests, in each day's test session at depth (6.6 ATA) was compared with performance in each day's control session at the last stop during decompression [1.3 ATA (10 fswg)]; performance at the 10 fswg decompression stop was not impaired relative to that at 1 ATA (4). Task performances improved across days, but the improvement for all tasks was comparable for the test exposures and control exposures, suggesting that adaptation had not occurred. Using a different set of tasks, but the same paradigm, Whitaker and Findley (5) also found performance at test and control depths followed parallel courses of improvement with repeated hyperbaric exposures.

These studies (3–5) used daily control measurements taken within the context of the hyperbaric exposure. We believe use of separate baseline measurements in close temporal proximity to each experimental measurement provides better control, for all extraneous factors that might produce improved performance with successive exposure to hyperbaric air, than do most other procedures. Measurements obtained at the end of formal training, or during control sessions that parallel the experimental ones in time, do not allow for the effects of all stresses present in hyperbaric air sessions, e.g., threat of bends or pulmonary embolism.

Despite the empirical evidence discussed above, personnel associated with operational diving apparently assume that narcosis diminishes with repeated exposures (6). Anecdotal support exists (7) for a diminution in narcosis with repeated exposures. Moeller et al. (3) offer possible insight into the apparent discrepancy between the empirical data and the anecdotal reports and operational observations; subjective measurements obtained during the experiment indicated a reduction in the narcotic effects of hyperbaric air with repeated exposures. Thus it is likely that the subjective feeling of a diminished effect of narcosis, accompanied by improving performance (without the advantage of the appropriate control measurements to help isolate the cause of the improvement), gives the impression that one is adapting to the effects of nitrogen narcosis.

It is not clear why subjective and objective measurements of adaptation to narcosis are not consistent (8). It might be that true behavioral adaptation to narcosis does occur but takes longer to manifest itself than subjective adaptation. To date, the maximum number of repeated exposures used in our controlled studies of adaptation to narcosis has been five. For the present study we assessed the effects of narcosis over 12 successive hyperbaric exposures to 5.5 ATA (148 fsw) for 30 min a day, using the same strategy to test adaptation to narcosis as the Moeller et al. (3) study, i.e., daily measurement of performance at both test and control depths during each hyperbaric exposure. (The main purpose of the experiment was to evaluate standard Navy decompression schedules for repetitive diving. The design and time allotments were beyond our control.)

METHOD AND MATERIALS

Performance on a single task, standing steadiness, was measured at 5.5 and 1.3 ATA during brief hyperbaric exposures on 12 consecutive days. A reduction in the magnitude of the difference between performances at 5.5 and 1.3 ATA across days (a day-×-depth interaction) was taken as the measure of behavioral adaptation to nitrogen narcosis.

Subjects

Six male staff members of the Naval Submarine Medical Research Laboratory (NSMRL), Groton, CT, ages 31–42, with a median age of 39, volunteered to participate in this experiment. All were hyperbaric chamber qualified.

Apparatus

Training and tests were conducted in the NSMRL hyperbaric chamber, which has been certified by the Naval Facilities Engineering Command for operation at pressures up to 10.62 ATA (350 fsw). This chamber is 2.74 m in diameter and is divided into a 3.96-m inner lock and a 2.44-m outer lock. The standing-steadiness test was administered in the inner lock using a Kristal model 9261A stabilimeter system. Data were digitized, and summated scores were computed and stored on-line by a Data General Nova 1220 computer.

Task

Although standing steadiness might not be commonly thought of as a "behavioral" measurement, it has shown a sensitivity to the effects of nitrogen narcosis comparable to other behavioral tests (3). It was used because, unlike many other behavioral measurements, it requires little training, is stable over time, and is at least as sensitive to the effects of nitrogen narcosis as a battery of other behavioral tests we have used. The administration of the test followed the procedures described by Adolfson et al. (9), and the method used was identical to that described in (3). Briefly, the subject was asked to stand as steadily as possible on the platform, in the Romberg position, and after a 20-sec rest interval, testing began. Four 70-sec trials were administered with 20-sec rest intervals in between. Two eyes-open and two eyes-closed trials were administered during each session, and digitized lateral and sagittal scores were computed for each trial.

Design and procedure

Subjects were tested in two replications of 3 subjects each. On each test day, subjects of a replication entered the hyperbaric chamber together and were compressed to 5.5 ATA for 30 min. Subjects were tested on the standing-steadiness test in random order during each test and control session. The control session was the 1.3 ATA-24 min decompression stop, during which test procedures were the same as for the 5.5-ATA session. The same procedure was followed for each of 12 successive days. Subjects were trained on the standing-steadiness task before the experiment to become familiar with the procedure.

The procedures prescribed by the U.S. Navy Diving Manual (U.S. Department of the Navy, 1973) for compression to depth and decompression from an air dive to 5.55 ATA for 30 min were followed.

RESULTS AND DISCUSSION

Results were analyzed with a mixed-design analysis of variance, with replication as a between-subject variable [2], and Day [12], Depth [2], Eye State [2], Body Plane [2], and Trial [2] as within-subject variables. The figures in brackets show the number of values for each variable. For example, 16 stabilimeter measurements were taken for each subject every day: at each of 2 depths, 2 trials were administered with eyes closed and 2 with eyes open; on every measurement, motion was recorded in two planes, lateral and saggital. Significant effects are reported in Table 1. The objective was to determine if there was an initial decrement in performance at 5.5 ATA compared to that at 1.3 ATA due to narcosis, and if it was ameliorated with repetitive exposures.

Figure 1 shows the mean body sway scores at 5.5 and 1.3 ATA during the 12 days. These scores are averaged across the other variables. Performance is worse (higher sway scores) at 5.5 ATA (1126, SEM = 33) than at 1.3 ATA (876, SEM = 29) on all 12 days ($P < 0.05$). The main effect of day was further assessed with a test for trends and Newman-Keuls postmortem tests; neither showed any significant effects.

Although it is not obvious from Fig. 1 whether adaptation to narcosis occurred (which would be evidenced by a convergence of the 148 and 10 fsw lines), the day-×-depth interaction was not significant ($F < 1.0$), indicating no change in the difference between performance at 148 and 10 fsw across days—that is, no adaptation to narcosis.

Other effects of hyperbaric pressure on standing steadiness found previously (3) were corroborated in this study. Mean body sway was significantly greater ($P < 0.05$) with eyes closed (1220, SEM = 38) than with eyes open (790, SEM = 21), and greater ($P < 0.01$) in the lateral (1246, SEM = 39) than in the sagittal (764, SEM = 22) plane. Further, the difference between lateral and sagittal plane scores was greater ($P < 0.05$) at 5.5 ATA than at 1.3 ATA. Several other interactions were significant (Table 1) but none seemed relevant to the aim of this study.

Since performance on the standing-steadiness test was impaired at 5.5 ATA compared to that at 1.3 ATA and showed other reliable effects found previously, we conclude that standing steadiness is a valid measurement for assessment of narcosis. We therefore infer that this experiment would have produced evidence for behavioral adaptation to narcosis if it does occur in repeated short exposures. The lack of evidence for a reduction in the magnitude of the impairment at the narcotic depth over repeated exposures indicates that short, repeated exposures, even when large in number, do not lead to behavioral adaptation to narcosis.

TABLE 1

STATISTICALLY RELIABLE EFFECTS ($P < 0.05$) IN 12 DAY EXPERIMENT AND STATISTICAL FINDINGS FOR TRIALS, REPLICATIONS, AND THE DEPTH-×-DAYS INTERACTION

Source (DF)	F	Comments $P < 0.05$ or less
Days (11,44)	2.078	
Depth (1,4)	133.568	
Trials (1,4)	4.182	ns
Eye-state (1,4)	19.190	
Plane (1,4)	25.056	
Replications (1,4)	0.107	ns
Depth days (11,44)	0.515	ns
Days-Trial-Replic (11,44)	2.128	
Days-Eyes (11,44)	2.047	
Depth-Plane (1,4)	9.243	
Eyes-Plane (1,4)	14.894	
Days-Depth-Plane-Replic (11,44)	2.581	
Days-Trial-Eyes-Replic (11,44)	2.083	
Days-Trial-Plane-Replic (11,44)	2.176	
Days-Eyes-Plane-Replic (11,44)	2.259	
Depth-Trial-Plane-Replic (1,4)	9.191	
Days-Depth-Trial-Eyes (11,44)	3.680	
Depth-Trial-Eyes-Plane (1,4)	13.308	
Depth-Tri-Eye-Pla-Rep (1,4)	3.429	

DF = degrees of freedom; F = *F* statistic.

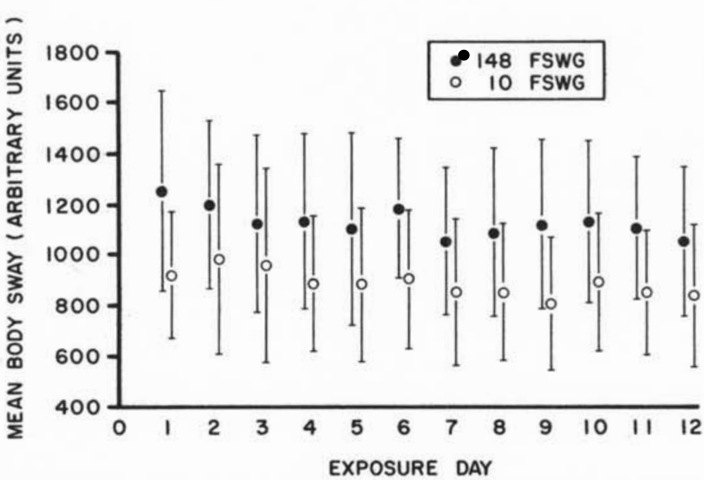

Fig. 1. Mean body sway and SD of 6 subjects at 5.5 ATA (148 fsw) and 1.3 ATA (10 fsw) during brief hyperbaric exposures over 12 consecutive days.

This conclusion is consistent with our previous study (3) but not with some anecdotal reports and common diving practices. As mentioned above, this could be explained by the existence of subjective adaptation (3) and for many tasks a general improvement in performance, independent of adaptation, with repeated dives. These phenomena in combination would give a diver a strong sense that he is adapting to the effects of nitrogen narcosis, when in fact, performance of tasks continues to be impaired relative to what it would be under normobaric conditions. In practice, if a diver feels that he is functioning normally when he is not, he is seriously at risk.

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